DTIC FILE COPY

(4)

AD-A211 284

TECHNICAL REPORT BRL-TR-3004

BRL

GUN TUBE/CHARGE/PROJECTILE INTERACTIONS AND GUN TUBE WEAR

D. L. KRUCZYNSKI
IRVIN C. STOBIE
MELINDA B. KRUMMERICH

JUNE 1989

U.S. ARMY LABORATORY COMMAND

BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

DESTRUCTION NOTICE

Destroy this report when it is no longer needed. DO NOT return it to the originator.

Additional copies of this report may be obtained from the National Technical Information Service, U.S. Department of Commerce, Springfield, VA 22161.

The findings of this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

The use of trade names or manufacturers' names in this report does not constitute indorsement of any commercial product.

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION: Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S): BRL-TR-3004	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION: USA Ballistic Research Laboratory; 6b. OFFICE SYMBOL (If applicable): SLCBR-IB-A	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code): Aberdeen Proving Ground, MD 21005-5066	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION: AMCCOM/PM-CAWS; 8b. OFFICE SYMBOL (If applicable): SMCAR-CW	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code): Picatinny Arsenal, NJ 07806-5000	10. SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO: ; PROJECT NO: 4111.16.2984; TASK NO.: 00; WORK UNIT ACCESSION NO: 00

11. TITLE (Include Security Classification)

Gun Tube/Charge/Projectile Interactions and Gun Tube Wear

12. PERSONAL AUTHOR(S)

David L. Kruczynski, Irvin C. Stobie, and Melinda B. Krummerich

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Technical Report	FROM Aug 86 TO Aug 87		

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	
19	06		Gun Wear, 155-mm Howitzer Wear, Asymmetric Wear; Thermocouple Data; M203A1 Propelling Charge.

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

During initial testing of the first US stick propellant charge for howitzer applications, the M203A1, an unusual asymmetric wear pattern developed. Virtually all wear which occurred during the 3000 round test was located in the top quadrant (10-2 o'clock) of the tube near the origin of rifling. Further complicating the analysis was the use of a "simulator projectile", the PXR6325, in lieu of the fielded M549A1 projectile for the wear study.

This study was initiated to determine if the PXR6325 projectile had unduly influenced the wear results and to determine how stick propellants differ from their granular counterparts in the processes producing gun tube wear. These questions were addressed in a three-pronged attack in which: a) historical US and NATO stick propellant wear data were analyzed; b) the two projectiles under study were compared using physical properties and finite element modeling; c) a matrix of test firings in a highly instrumented gun tube was conducted to measure properties such as heat transfer and gun tube strain at various circumferentially separated points of interest.

As a result of these efforts, the contributions of the stick charges and different projectile designs on asymmetric gun wear were discerned. Using these data, the results of a subsequent stick charge wear retest using a new gun tube and a different projectile were accurately predicted. tube wear

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION: Unclassified	
22a. NAME OF RESPONSIBLE INDIVIDUAL: David L. Kruczynski	22b. TELEPHONE (Include Area Code): (301) 278-6202	22c. OFFICE SYMBOL: SLCBR-IB A

DD Form 1473, JUN 86 — Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

TABLE OF CONTENTS

LIST OF FIGURES

Figure | Page

LIST OF TABLES

I. INTRODUCTION

Unusual gun wear patterns developed during product improvement tests of the US Army's first stick propellant artillery charge, the M203A1.[1] The 155-mm, M199 gun tube showed very little wear except at the top of the gun tube (10 to 2 o'clock) adjacent to the origin of rifling. This wear pattern differs considerably from wear patterns historically produced by ballistically comparable granular charges which, while more erosive, generally produce circumferentially uniform wear patterns.

Although the M203A1 charge was shown in this and later tests to extend useful tube life by better than a factor of two, as compared with comparable granular charges, two serious questions remained:

- *Had the use of a simulator projectile, the PXR6325, in lieu of the fielded M549A1 projectile, unduly influenced the results?*

- *If the PXR6325 did not affect the wear results, what did account for the unusual wear pattern and why had the gun tube's useful life exceeded the most optimistic expectations?*

A. Background

The M203A1 is the lead charge in US developmental efforts to replace granular propellants with stick propellants in howitzer applications. Figures 1 and 2 compare the M203 granular charge with its replacement, the M203A1. Note that while the charges are ballistically equivalent (i.e., produce same projectile muzzle velocities), the new M203A1 charge differs in virtually every other way, including propellant formulation, configuration, ignition system, and type of propellant encasement.

One major improvement promised by the M203A1 was reduced gun tube wear due to its lower flame temperature propellant formulation (400 degrees K lower as compared to the M203 granular charge). An extensive wear test of 2902 rounds was fired to demonstrate the wear rate. Since the M203 series charge is the Army's current maximum range charge, it would be fired principally with the current maximum range projectile, the M549A1. However, in an effort to save costs and due to the unavailability of large quantities of inert M549A1 projectiles, a substitute or simulator projectile, the PXR6325, was used.

The PXR6325 projectile is an M107 projectile banded with a M549A1 rotating band and obturator. The simulator projectile is then inert-filled to the average weight of an M549A1. Differences in projectiles include wheelbase and total length, projectile wall thickness, and boattail design. A comparison photograph of the two projectiles appears in Figure 3.

Virtually all large howitzer wear tests follow a scenario of firing several hundred expenditure rounds with the primary charge under study and a primary projectile often

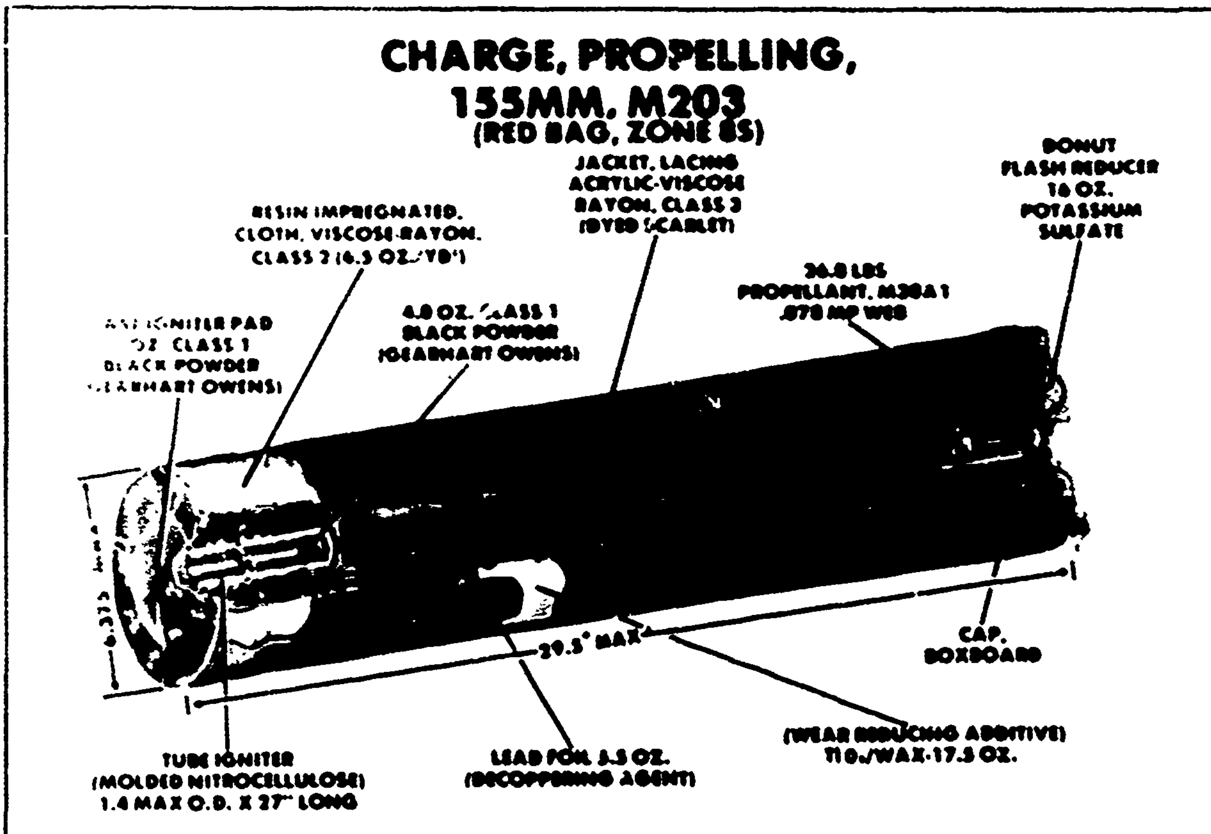


Figure 1. M203 Granular Propelling Charge

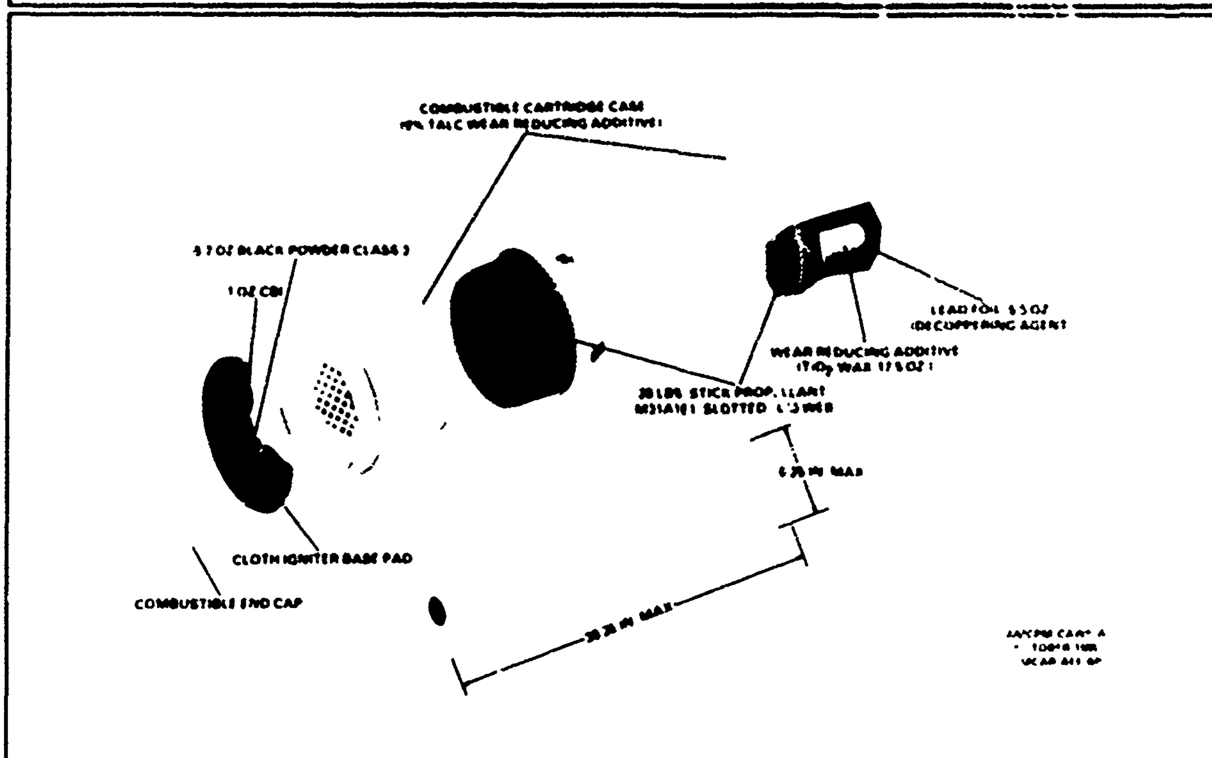


Figure 2. M203A1 Stick Propelling Charge

chosen for economic or convenience reasons. The gun tube is then inspected and a smaller group of mixed charge/projectile combinations is fired to check accuracy, fuze function, velocity, and accuracy. This procedure is repeated until loss of accuracy, fuze malfunctions, band stripping, or other abnormalities suggest end of useful tube life.

In the remainder of this paper, references to a primary charge or projectile will refer to the charges and projectiles fired as expenditure or "wear" rounds. This combination makes up the large majority of the gun tube's total round count at end of tube life or cessation of testing. For the gun tube of interest in this paper, the M203A1 and the PXR6325 were the primary charge and projectile respectively.

The M203A1 worn gun tube (serial # 30093) began to show measurable asymmetric wear as early as 200 rounds. This asymmetric wear became visually apparent at 800 rounds and continued to increase as testing progressed. Although the gun tube still delivered projectiles accurately and safely at the cessation of testing (2902 rounds), asymmetric wear was quite severe at the origin of rifling. Figure 4 illustrates this wear and its progressive nature.

B. Theories and Approach

Causes for gun tube wear in general can be broken down into three primary classes; heat, friction, and chemical reactions. Figure 5 displays how these parameters could be involved in the production of asymmetric wear previously described. Note also the potential interplay of the projectile.

Figure 3. M549 and PXR6325 Projectiles

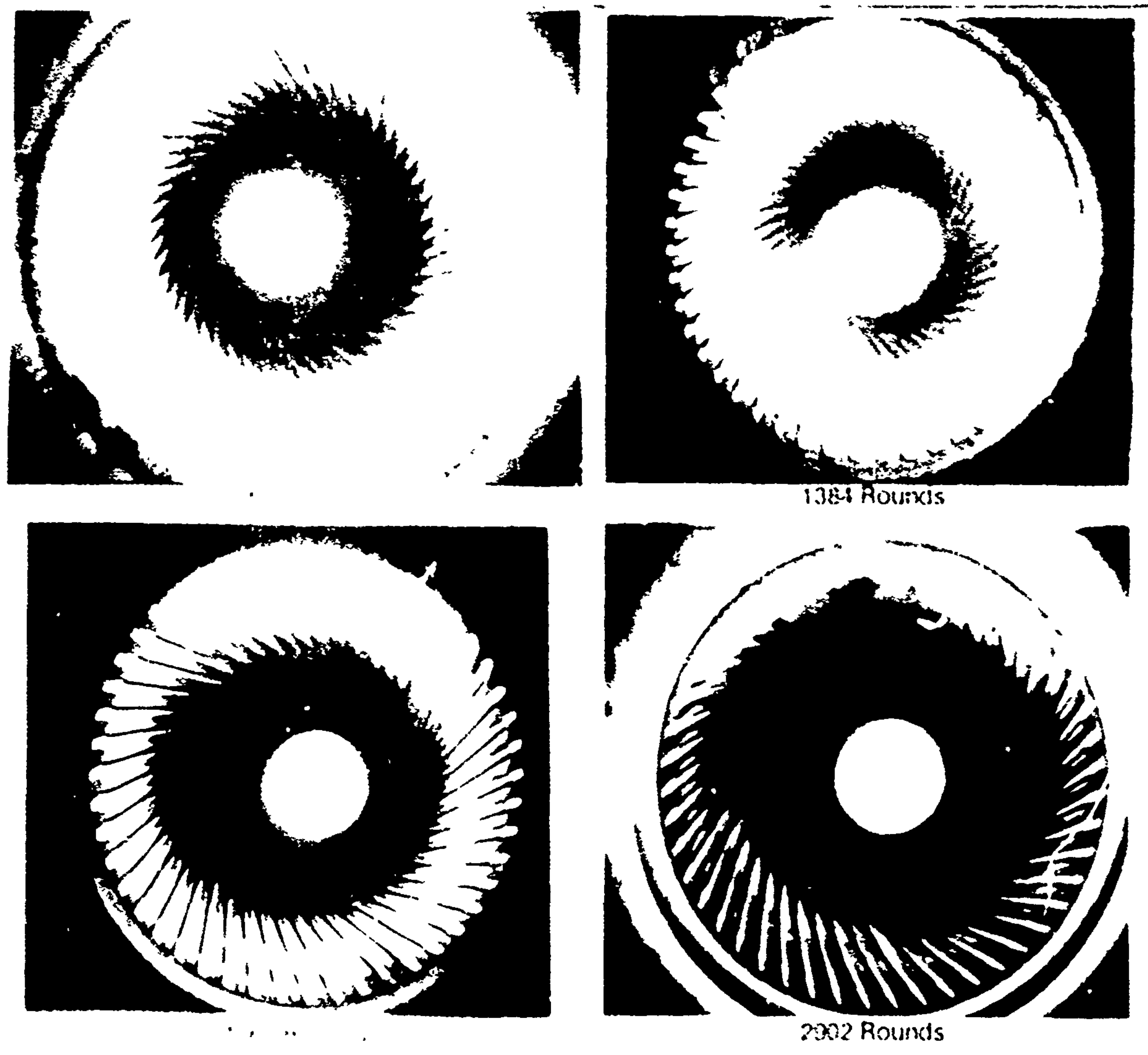


Figure 4 Gun Tube Worn With M203A1 Stick Propelling Charges

In addition to these general wear mechanisms, it was theorized that the basic design of the M203A1 charge could be contributing to the asymmetric wear phenomenon. The M203A1's use of stick propellant allows for rapid and unimpeded flow of combustion gases through the length of the charge, resulting in rapid pressurization within the gas impermeable combustible case. The combustible case may then burst at the top where sufficient ullage exists for the case to move radially outwards. The TiO_2 wear liner, which is wrapped around the propellant, would also be forced apart and away from the top of the tube in a similar fashion. The fast moving, hot propulsive gases would then have direct access to the top of the gun tube now virtually unprotected by wear reducing additives. This hypothesis is shown schematically in Figure 6. Note that granular charges previously used in US wear studies have neither the accommodating gas flow channels of stick charges nor the impermeable combustible case to deal with.

This investigation was designed to look at two of the general wear contributors, heat and friction, while keying on the theory involving charge composition and positioning.

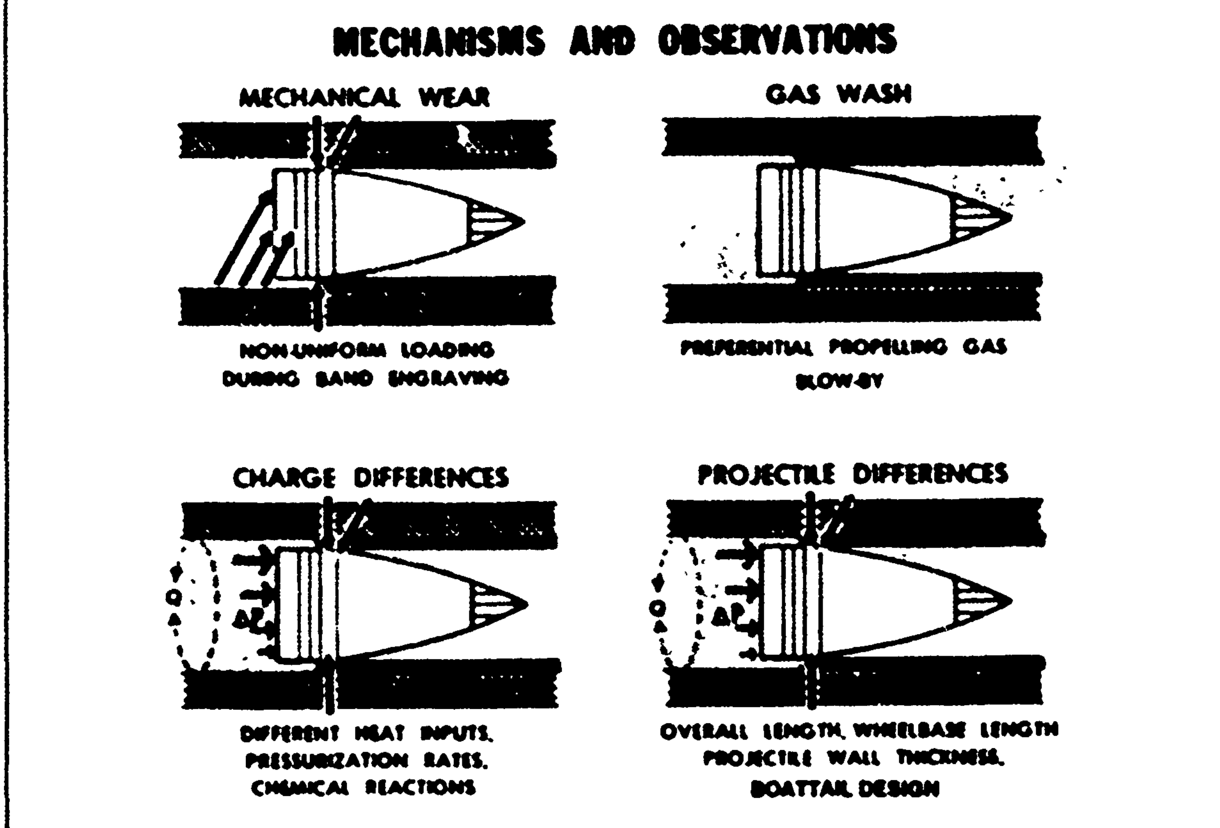


Figure 5. Potential Causes of Asymmetric Wear Phenomenon

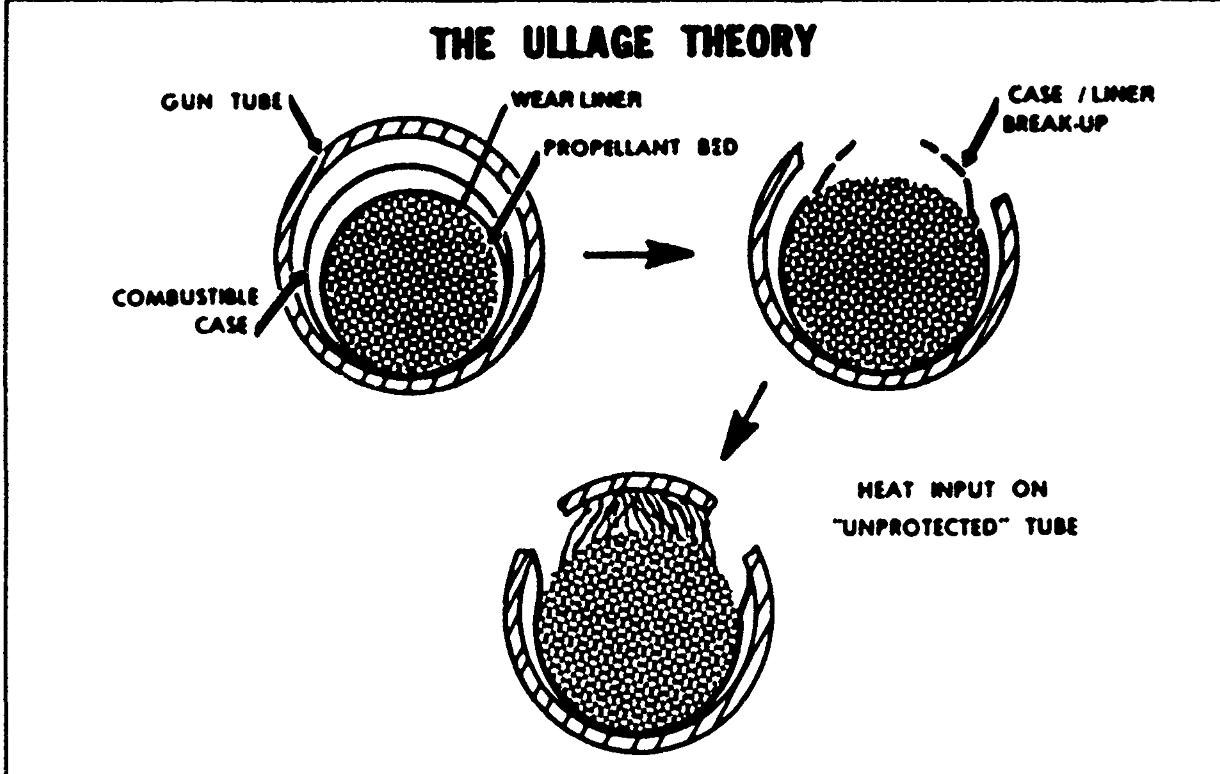


Figure 6. Postulated Effects of Ullage on Asymmetric Wear

Chemical reactions provoking gun tube wear were not considered primary causes in producing asymmetric wear and are not further addressed. In addition historical gun wear patterns of both US and foreign gun tubes were examined.

II. LABORATORY RESEARCH

For clarity, the various investigative procedures, instrumentation techniques, and subsequent results are presented separately where appropriate. Comprehensive observations and conclusions are then drawn.

A. Historical Gun Wear Analysis

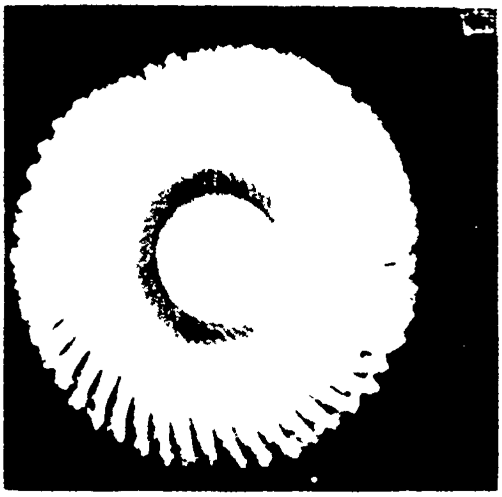
Stick propellants are new to US artillery charge inventories. Therefore, there are no US tubes previously worn with stick charges for comparison with those worn with granular charges. As noted, previous granular versions of the M203A1 charge had displayed uniform circumferential wear patterns. The granular charge was also shown to be more erosive to the origin of rifling than the stick charge.

Additionally, granular charge worn tubes generally display a second worn area located roughly 46 cm (18 inches) forward of the primary wear area at the origin of rifling. This secondary wear, which contributes to fuze and rotating band failures, did not occur in the tube worn with stick propellants.

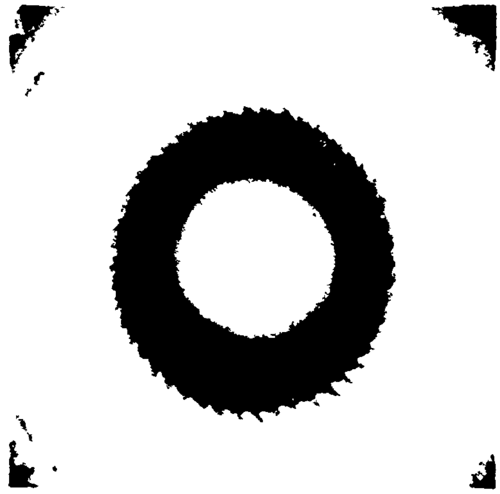
Figure 7 displays the origin of rifling for three typical 155-mm gun tubes fired to end of life with granular propellants. Note that in contrast to the tube worn with stick charges displayed in Figure 4, the wear pattern is circumferentially uniform. Figure 8 graphs the total vertical versus horizontal wear for the three tubes worn with granular charges of Figure 7 and the tube worn with stick charges (#30093). Note again that while the total wear in the vertical plane is roughly the same for all the tubes, it is concentrated at the top of the tube only for the stick charge worn tube. Also notable is the relative lack of horizontal wear in this tube.

Cases of asymmetric wear in NATO 155-mm gun tubes firing stick charges have been documented. Reference 2 contains a set of stargage records from gun tube PT 09 from which 2096 of the 3047 rounds fired were Cartridge III stick charges, which are the ballistic equivalent of the M203A1. Figure 9 compares the first inch of rifling wear in the horizontal and vertical planes to similar data for the tube worn with US stick charges. Note that while the absolute magnitudes of the wear patterns differ, both tubes show similar differences in vertical versus horizontal wear profiles.

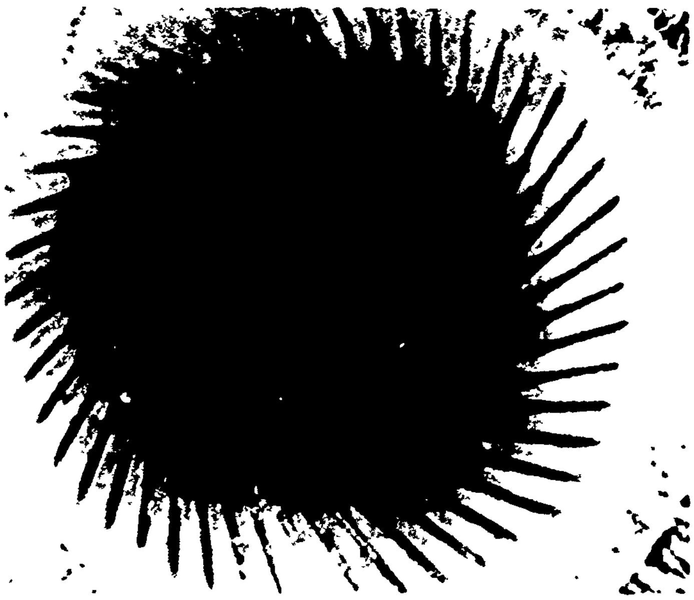
These data alone do not verify that the NATO tube was excessively worn at the top, since it could be worn at the top and bottom of the tube and show a similar profile. The confirmation of concentration of wear at the top of the tube follows from a translation of the comments portion of the German stargage records for gun tube PT 09 which appears in Reference 2. A rough translation follows;



Primary projectile-M483; tube #27687 @ 2054 rounds



Primary projectile-M483; tube #03 @ 1981 rounds

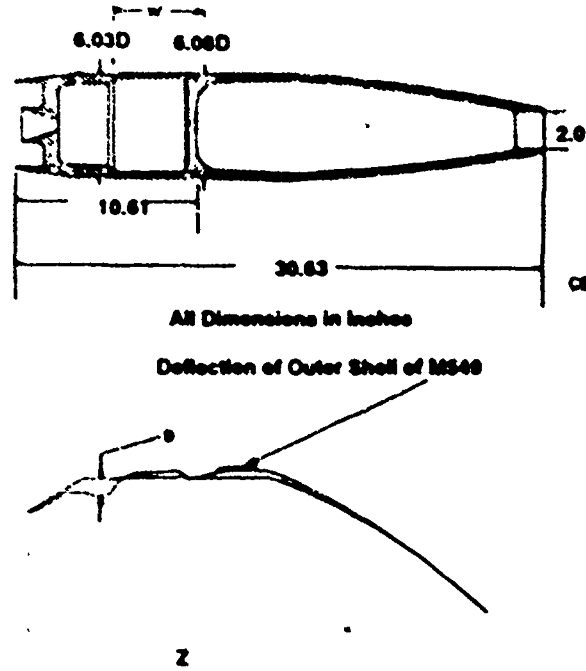


Primary projectile-M549; tube #77 @ 2000 rounds

Figure 7. Gun Tubes Worn With M203 Granular Charges

"Beginning at 650 mm from rear face of tube (RFT) in the chamber area at 12 o'clock the diameter is increased as compared to before. From the beginning of rifling and up to 100 mm between 10 & 12 o'clock the lands are obviously smooth. Up to 1500 mm from RFT the lands are eroded, between 10 & 12 o'clock. The inside radius of the groves at 10 to 12 o'clock are rounded to 2500 mm from RFT."

Besides these data, conversations with a representative from the UK reveal that they have more recently experienced asymmetric wear when firing their howitzer's top zone stick charge.[3] This asymmetric wear is apparently more severe than that incurred in M203A1 testing. The increased severity may be caused by the lack of both an obturator on the projectile and a titanium dioxide (TiO_2) wear liner in the charge.



AVERAGE MEASURED PROPERTIES

CENTER OF GRAVITY (INCHES FROM BASE)	WEIGHT (LB)	MOMENTS OF INERTIA: AXIAL	TRANSVERSE
12.79	95.6	3.52	43.77

Figure 10. Physical and Measured Properties - M549A1 Projectile

defection in the rotating band area for the M549A1 projectile 0.33mm (0.013 in.), almost twice that of the PXR6325 0.18mm (0.007 in).

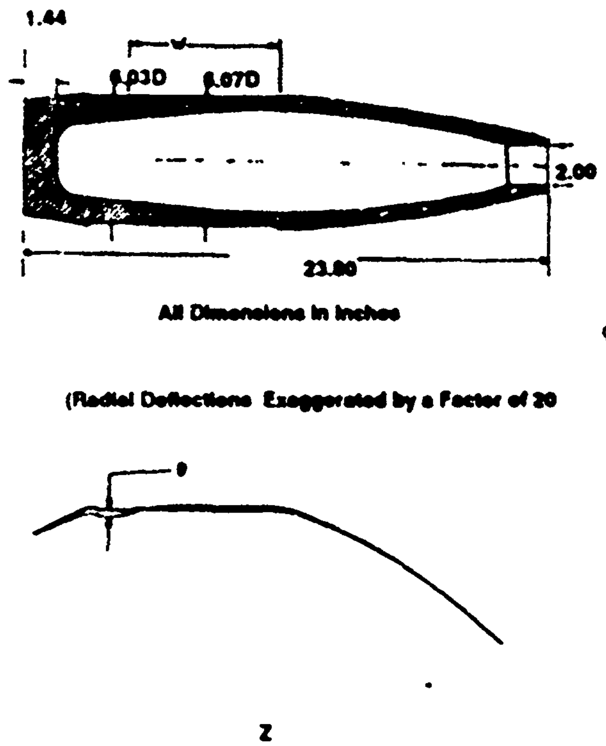
This difference of 0.152 mm (0.006 inches) is, however, relatively small compared with the deformations of the rotating band and obturator during engraving. Additional details regarding the projectile modeling study are available in Reference 4.

III. TEST FIRINGS

To evaluate the relative differences in heat input, gun tube strain, and rotating band/obturator performance of the various projectile-charge combinations a matrix of firings was conducted in a heavily instrumented M199 155-mm gun tube. A schematic view of the instrumentation employed appears in Figure 12. The matrix of firings conducted is shown in Table 1. For clarity, the results of the firings are presented seperately for the individual instrumentation techniques.

A. High Speed, Closeup, Downbore Photography

It was suspected that localized rotating/obturator band failure with resultant gas leakage (blow-by) could have produced asymmetric wear patterns. Currently available technology existed only for obtaining overview photography of the projectile exiting the muzzle.



AVERAGE MEASURED PROPERTIES

CENTER OF GRAVITY (INCHES FROM BASE)	WEIGHT (LB)	MOMENTS OF INERTIA [illegible] AXIAL	MOMENTS OF INERTIA [illegible] TRANSVERSE
9.44	95.6	3.43	29.70

W ([illegible]) = [illegible]
D ([illegible]) = [illegible]

Figure 11. Physical and Measured Properties - PXR6325 Projectile

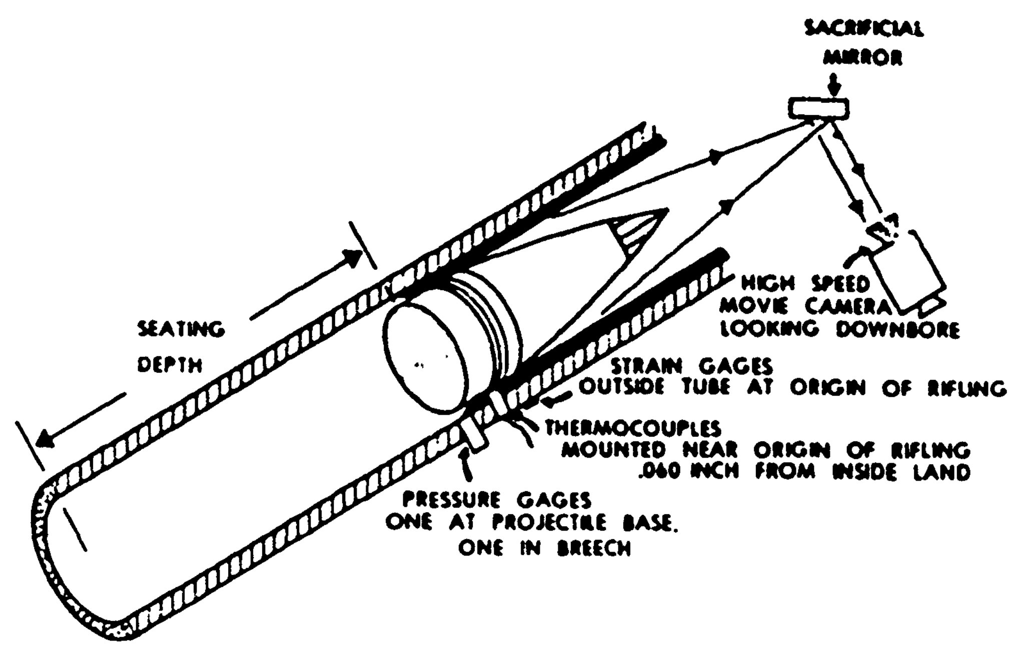


Figure 12. Schematic of Test Firing Instrumentation

These techniques, developed as multipurpose obturator/sabot discard/yaw indicators, were of insufficient resolution for detailed inbore studies. In addition, since the camera and mirror were mounted some distance in front of and on the same plane as the weapon, they were only useful if the weapon remained within a few mills of zero elevation.

Table 1. Matrix of Firings

PROJECTILE	CHARGE	SAMPLE SIZE
[illegible]	M203 GRANULAR	[illegible]
[illegible]	M203 GRANULAR	[illegible]
[illegible]	M203A1 STICK	[illegible]
[illegible]	M203A1 STICK	[illegible]
[illegible]	M203A1 STICK *	[illegible]

*These charges were intentionally held upwards in the gun chamber to reduce the ullage at the top of the chamber.

To overcome these limitations, a device was developed which allows extremely closeup, downbore photography at any gun elevation and with little danger to the camera itself. The system consists of a pair of brackets welded to the bottom sides of the muzzle brake. From these brackets, two arms can be bolted at various heights below and extending forward of the muzzle brake. A mirror platform which can pivot 360 degrees normal to the line of fire is mounted to these arms roughly one meter (3.28 ft) from the end of the muzzle brake. This platform is held in a horizontal position before firing by wooden dowel rods which extend through the mounting arms and into the mirror platform. A vice with adjustable clamps holding a mirror is then bolted to the mirror platform.

A high speed camera equipped with a telephoto lens is mounted behind and above the weapon, which with proper mirror adjustment can "look" directly downbore. The camera records any luminous activity inbore until the projectile exits. When the projectile nears the mirror, the shock wave preceeding the projectile is sufficient to shear the retaining dowel rods, allowing the mirror platform and vice to rotate clear of the projectile. Any additional blast energy is dissipated by the apparatus in harmless rotation. The dowel rods and mirror are of course sacrificed; however, little additional damage is inflected on the device. Figure 13 displays this device.

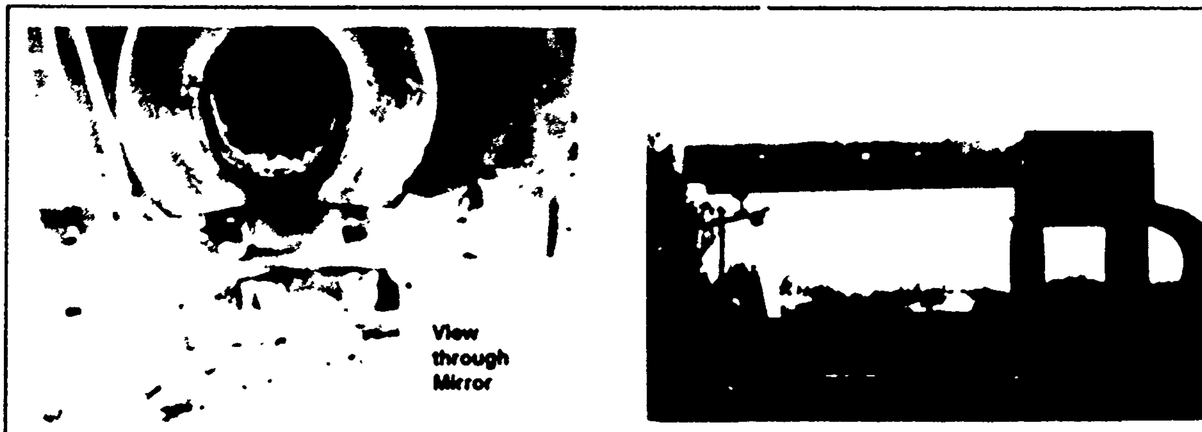


Figure 13. High Speed, Closeup Photography Device

Sufficient photographic results were obtained to determine that there were no obturator failures resulting in luminous blow-by with either projectile. It should be noted that the test gun tube was new and would be expected to produce obturation superior to that of a worn tube. However, the original asymmetrically worn gun tube showed definite signs of uneven wear as early as 300 rounds, suggesting that this uneven wear production is triggered very early in the gun tube's life.

Figure 14 shows a series of frames from a high speed camera, running at 5000 frames per second, of a M549 projectile fired with a M203A1 stick charge exiting the gun tube. It is noted that no illumination is seen in or around the gun tube until the projectile is starting to exit the muzzle. This was typical of the photographic results obtained.

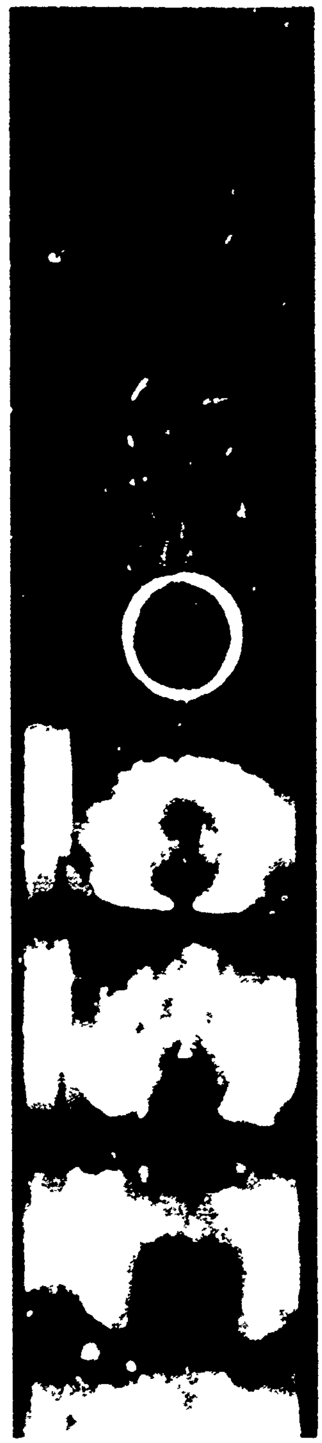


Figure 14. M549 Projectile Exiting Muzzle

B. Pressure and Strain Gage Data

Four surface mounted 350-ohm strain gages were mounted on the outside surface of the gun tube. They were located 90 degrees apart just forward of the origin of rifling. From the breech of the weapon using clock coordinates to denote circumferential position, strain gages were located at 12, 3, 6, and 9 o'clock. The strain on the exterior of the gun tube at these positions was then recorded as a function of time during the ballistic cycle.

Standard chamber pressure time responses were recorded with Kistler 607 gages located at the breech and forward ends of the gun chamber. Table 2 presents an average of the chamber pressures and peak strains recorded at each position, an average of all positions, and the differences in maximum strains recorded at the top and the bottom of the gun tube.

Table 2. Pressure and Strain Gage Data

CHARGE PROJECTILE	CHAMBER PRESSURE (MPa)		STRAIN BY GAGE POSITION (microstrain)				AVG	VERT DELTA
	REAR	FOR	12	3	6	9		
GRANULAR M549	47.7	43.3	[illegible]	1000	[illegible]	[illegible]	[illegible]	105
GRANULAR / PXR6325	48.0	42.9	[illegible]	1010	1077	[illegible]	[illegible]	133
STICK/M549	51.7	45.5	1007	1073	1076	1104	[illegible]	[illegible]
STICK/PXR6325	52.0	46.0	[illegible]	[illegible]	[illegible]	1111	1071	[illegible]
STICK/M549 CHARGE HELD AT TOP OF CHAMBER	53.1	45.8	[illegible]	[illegible]	[illegible]	1113	[illegible]	[illegible]

AVG = AVERAGE OF 12, 3, 6, 9 O'CLOCK GAGES
VERT DELTA = 12 MINUS 6 O'CLOCK POSITIONS

Several observations can be made from the data in Table 2:

- *The PXR6325 projectile tends to induce slightly larger tube strains for both stick and granular charges, indicative of its stiffer sidewalls.*

- *The higher average strains recorded for the stick charge firings result from its typically higher chamber pressure, 27.6 MPa (4 kpsi).*

- *The vertical delta (top minus bottom gage) values are lower for the stick charge firings than for the granular charge firings. This would tend to indicate that there is not a frictional or mechanical contributor to the production of asymmetric wear with the M203A1 stick charge firings.*

Table 2 presents only the peak strain obtained at each position during firings. In each of these records, the peak was taken from strain versus time plots very similar in appearance to a pressure versus time curve.

Figures 15 and 16 contain typical unfiltered plots of tube strain versus time for stick and granular charges, respectively. The strain rise produced with the stick charge is uniform and smooth. The strain rise produced with the granular charge, however, includes a stepped portion located nearly two thirds of the way up the curve. The step occurred in **all** granular charge firings regardless of gage position or projectile used. Conversely, this anomaly never occurred in any firings of the stick charge. The anomaly was verified on many occasions.

An examination of the chamber pressure versus time records in these instances yield no discernible relationship. One explanation for such an event is that the strain gage is detecting a relaxation of tube strain as the projectile moves away from the charge which has been compacted against the projectile base early in the ballistic cycle. Granular

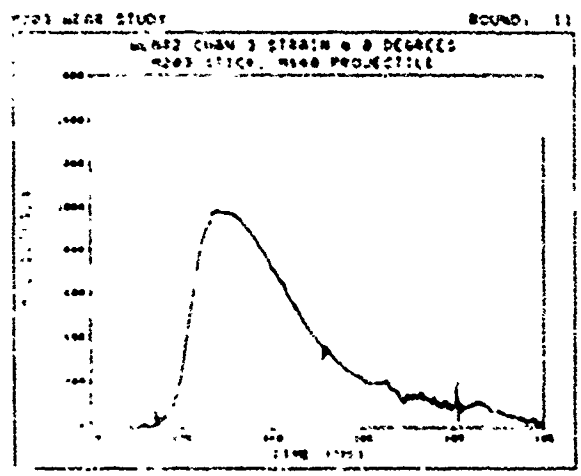


Figure 15. Tube Strain Plot with Stick Charge

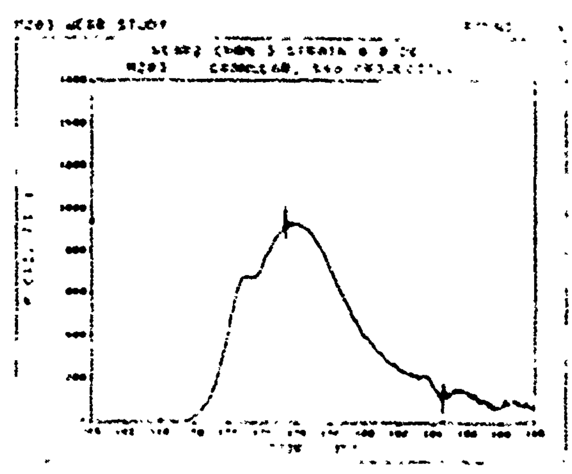


Figure 16. Tube Strain Plot with Granular Charge

charges have been shown to be accelerated during flamespreading to impact the projectile base.[5] The effects, if any, of this event on gun tube wear and wear patterns are not known.

C. Thermocouple Data

1.59-mm (1/16 in.) diameter holes were drilled in the test gun tube in four places 90 degrees apart just forward of the origin of rifling and slightly behind the strain gages. As with the strain gages they were located at 12, 3, 6, and 9 o'clock as viewed from the breech of the weapon. An additional thermocouple at 12 o'clock was later installed 152.4 cm (60 in.) from the rear face of the gun tube or 46.4 cm (18.3 in.) from the origin of rifling. This location is often termed the secondary wear point as granular charges have historically produced aggravated wear in this area.

The thermocouple holes were drilled as follows. First, pilot holes were drilled through the tube wall near each desired thermocouple location. The thickness of the gun tube wall was then precisely measured before drilling the actual thermocouple hole to 1.5 mm (0.060 in.) from the surface of the rifling grooves. These very small pilot holes were then plugged before firing.

Insulated constantan wires were welded to the bottom of each hole to form gun tube steel-constantan thermocouple junctions. To insure the accuracy of the machining operation and to further calibrate the thermocouples, the gun was inverted 180 degrees from its normal position for some of the firings. The thermocouples at 12 and 6 o'clock were then analyzed for relative performance under the same firing conditions but at differing vertical locations. Small normalizing corrections could then be applied. Figure 17 depicts a typical unfiltered thermocouple record for a stick charge firing. Note the readily discernible thermocouple junction failure at the 9 o'clock gage position, as indicated by failure of the curve to decay after reaching peak temperature.

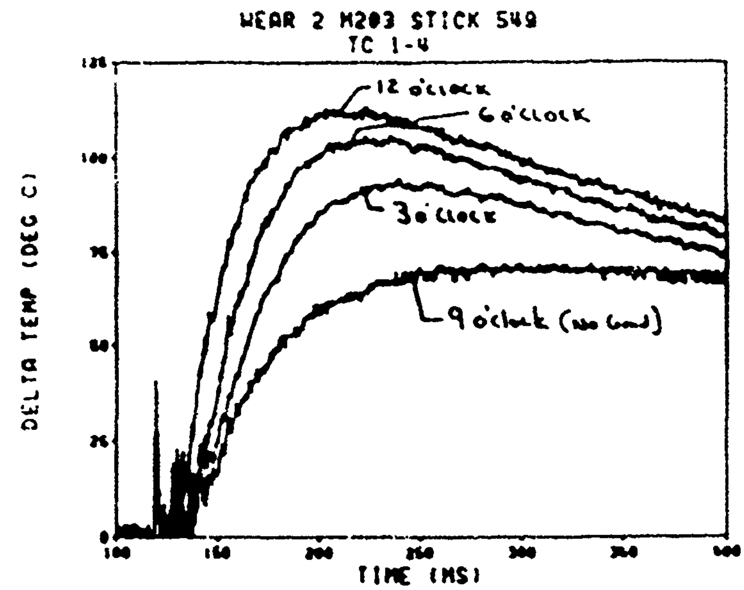


Figure 17. Typical Thermocouple Response Curves

A summary of the thermocouple data for the various conditions tested appears in Table 3. Note that the vertical temperature difference (12 minus 6 o'clock) is considered a primary indication of the ability to produce asymmetric wear. This asymmetric wear effect is highlighted in Figure 18.

Table 3. Thermocouple Data

TEMPERATURE CHANGE (DEGREES C)
BY SENSOR POSITION (CLOCK CORD.)

PROJ.	12	3	6	9	DB	AVG.	VERTICAL DELTA
M203 GRANULAR PROPELLANT							
M549	113	95	110	94	68	104	3
PXR6325	126	108	125	LOST	75	120	1
*** M203A1 STICK PROPELLANT ***							
M549	112	84	97	90	64	99	15
PXR6325	116	92	108	93	71	106	8
M203A1 STICK PROPELLANT - CHARGE HELD UP TO TOP OF CHAMBER							
M549	103	89	102	87	69	95	1

DB - DOWNBORE THERMOCOUPLE, LOCATED [illegible] INCHES FROM REAR FACE OF GUN TUBE AT 12 O'CLOCK. ALL OTHERS LOCATED AT ORIGIN OF RIFLING.

AVG - AVERAGE OF 12, 3, 6 & 9 O'CLOCK THERMOCOUPLES

VERT DELTA - TOP MINUS BOTTOM THERMOCOUPLE

GRANULAR PXR AVG. ASSUMES 9 O'CLOCK = 3 O'CLOCK FOR DATA CONSISTENCY

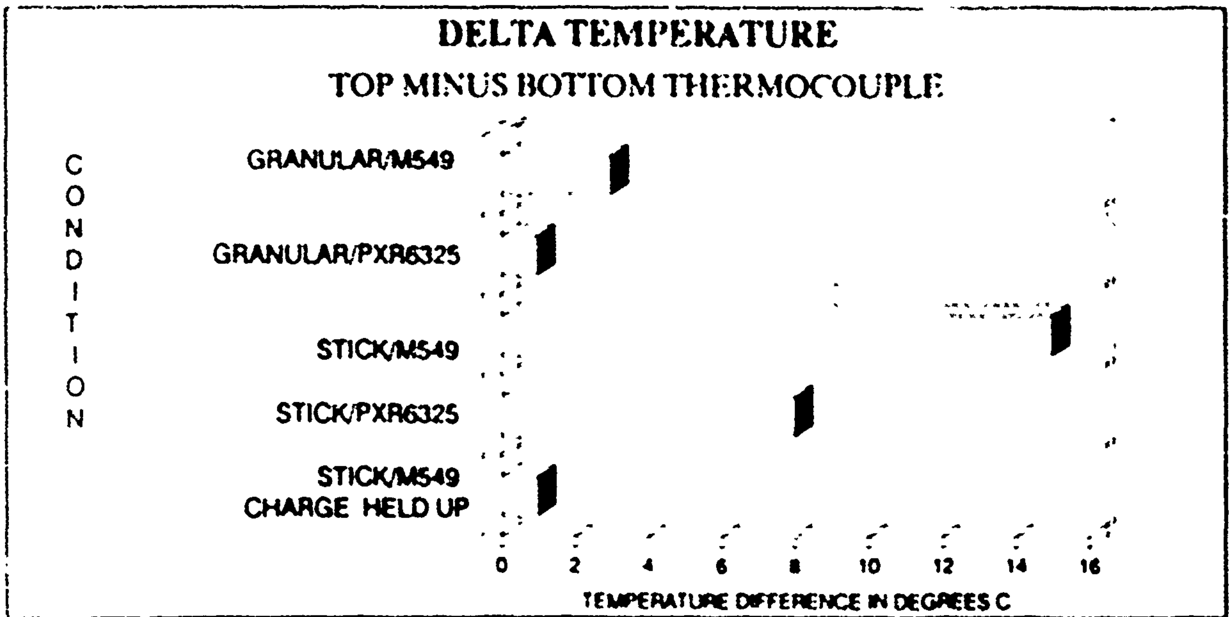


Figure 18: Asymmetric Tube Heating Data

The following observations on the data in Table 3 and Figure 18 are noteworthy:

- *The differance in temperatures between top and bottom thermocouples confirms experimentally that the tendency to produce vertical asymmetric wear is a stick charge phenomenon related to uneven heat distribution.*

- *The difference in temperatures (top minus bottom) for the firings conducted with the charge in its normal position compared with firings where the charge was propped up against the top of the chamber reveals that the presence of ullage has a dramatic effect on the distribution of heat during firing.*

- *The stick charge firing data for both projectiles reveals that the M549 firing group displays a higher difference in temperatures between the top and bottom thermocouples, suggesting that asymmetric wear with this projectile may be higher than with the PXR6325 projectile*

V. CONCLUSIONS

Assimilating the results from historical records, projectile comparisons, and experimental firings, the following conclusions are drawn:

- *Use of the PXR6325 projectile does not exacerbate asymmetric gun tube wear when fired with the M203A1 stick propelling charge. In fact, data show that asymmetric wear may be higher when using the M549 projectile.*

- *The propensity to produce asymmetric wear in howitzers appears to be a stick charge phenomenon. In addition, the asymmetric heating pattern caused by stick propelling charges is directly related to the presence of ullage between the charge sidewall and the gun tube wall, as described earlier.*

V. EPILOGUE

Two events of considerable interest to this study have occurred since its completion.

First, the original gun tube used in the M203A1 testing has had an additional 800 + rounds successfully fired in it. This gun tube had already surpassed the average life of granular worn tubes (1700 rounds) by 1200 rounds before these firings. The additional increase in tube life was obtained despite the severe asymmetric wear pattern which continued to increase in depth and started to enlarge circumferentially. The gun tube (#30093) is still considered operational having fired to date 3726 rounds (3526 Equivalent Full Service Charges, EFC).

The continued operational success of this gun tube has prompted thoughts about the potential merits of asymmetric versus circumferentially uniform wear.

Granular charge worn tubes are uniformly worn radially causing the projectile to be subjected to a continually degraded environment for initial engraving and obturation. As the lands wear, there is less and less initial contact between the projectiles rotating band and the first few centimeters of rifling. The projectile will eventually compensate somewhat for these effects by seating farther downbore, but this is only partially effective. Thus, during initial acceleration, the projectile runs sloppily down the tube before suddenly encountering "intact lands" where it receives a rotational jolt. This effect, generally known as torsional impulse, plays a large role in fuze failures, rotating band striping, and to some degree, loss of accuracy. This phenomenon is of particular concern to the nuclear projectile community.

St' k charge worn tubes of the M203A1 configuration appear to delay the onset of or totally circumvent this failure mechanism by concentrating their wear path in the top quandrant of the gun tube. In essence, the loss of a localized area of lands still leaves the bulk of the gun tube intact for initial engraving contact. It was thought that this localized erosion path might eventually lead to intolerable losses in projectile velocity through loss of propulsive gases. In fact, however, velocity losses for the stick propellant worn tube at 3500 EFC are equal those incurred in granular charge worn tubes at 1800 EFC. It is appears that the nylon obturator is capable of maintaining an adequate seal even in an asymmetrically worn tube.

It is likely then that efforts to reduce the asymmetric wear by simply redistributing it uniformly would be counterproductive. Efforts which decrease the severity of asymmetric wear without increasing it elsewhere, however, will increase the probability of obtaining the ultimate goal of a gun tube with a useful life approaching that of the weapon system.

The second event which occurred since the completion of the studies reported in this paper was a second wear test using the M203A1 charge. To date 1000 rounds have been fired in a new gun tube in this test. One major difference in this second wear study was the use of the M549A1 projectile in lieu of its simulator, the PXR6325, used in the original wear test.

The advantages of using the M549 projectile in the second wear test were twofold. First, confirmation that the asymmetric wear problem was a stick charge phenomenon could be obtained. Second, data which showed that the M549 would induce higher levels of asymmetric wear could be verified.

Comparison plots of vertical and horizontal wear at similar round counts for both wear tests appear in Figure 19.

Readily apparent in Figure 19 are the obvious asymmetric wear profiles of both gun

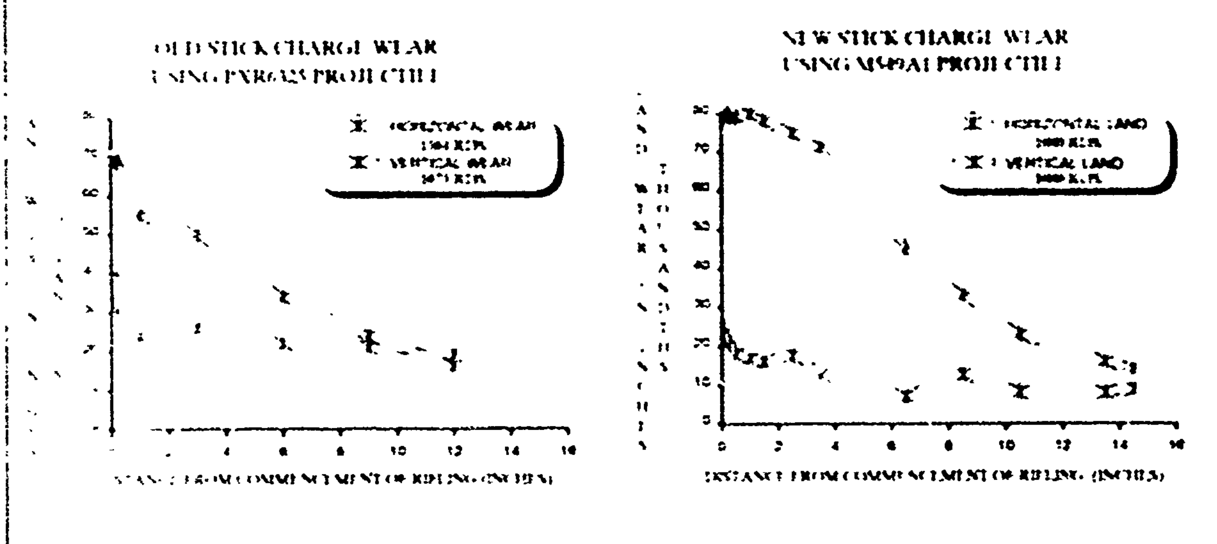


Figure 19 Wear Data For Gun Tubes Worn With Stick Propellant Charges

tubes. Again, stargage report comments confirm that the bulk of the wear is in the top quadrant in the second gun tube. Note also that the asymmetric wear profile (higher vertical wear) is more pronounced in the gun tube firing the M549A1 projectile as was predicted. The horizontal wear profiles when normalized for equivalent round counts would be roughly equal.

These results indicate that the useful life of an M199 gun tube firing M203A1 stick charges with M549A1 projectiles will be lower than for the same tube using the M203A1 with the PXR6325 Projectile. However, due to the innocuous effects of asymmetric wear, tube life under these conditions should still be improved as compared with wear produced by the M203 granular propellant charge.

REFERENCES

1 David L. Kruczynski, "Final Report of Product Improvement Test of 155-mm Propelling Charge M203E2," Report No. USACSTA-6329, USA Combat SystemsTest Activity, Aberdeen Proving Ground, MD, January 1986.

2 J. R. Ward, "Comparisons of Wear Between the 155-mm Cartridge 3 Charge in the FH70 Howitzer and the M203 Charge in the M199 Howitzer," Report No. ARBRL-MR-03172, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, May 1982.

3. Private Communication, Andrew Beedle, RARDE, UK, February 1986.

4 Melinda Krummerich, "Stress Analysis of the M549 and PXR6325 Projectiles," Report No. BRL-MR-3633, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, August 1987.

5. Thomas C. Minor, "Characterization of Ignition Systems for Bagged Artillery Charges," Report No. ARBRL-TR-02377, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, October 1981.

No of Copies	Organization
(Unclass., unlimited) 12 (Unclass., limited) 2 (Classified) 2	Administrator Defense Technical Info Center ATTN: DTIC-DDA Cameron Station Alexandria, VA 22304-6145
1	HQDA (SARD-TR) WASH, DC 20310-0001
1	Commander US Army Materiel Command ATTN: AMCDRA-ST 5001 Eisenhower Avenue Alexandria, VA 22333-0001
1	Commander US Army Laboratory Command ATTN: AMSLC-DL Adelphi, MD 20783-1145
2	Commander Armament RD&E Center US Army AMCCOM ATTN: SMCAR-MSI Picatinny Arsenal, NJ 07806-5000
2	Commander Armament RD&E Center US Army AMCCOM ATTN: SMCAR-TDC Picatinny Arsenal, NJ 07806-5000
1	Director Benet Weapons Laboratory Armament RD&E Center US Army AMCCOM ATTN: SMCAR-LCB-TL Watervliet, NY 12189-4050
1	Commander US Army Armament, Munitions and Chemical Command ATTN: SMCAR-ESP-L Rock Island, IL 61299-5000
1	Commander US Army Aviation Systems Command ATTN: AMSAV-DACL 4300 Goodfellow Blvd. St. Louis, MO 63120-1798
1	Director US Army Aviation Research and Technology Activity Ames Research Center Moffett Field, CA 94035-1099

No of Copies	Organization
1	Commander US Army Missile Command ATTN: AMSMI-RD-CS-R (DOC) Redstone Arsenal, AL 35898-5010
1	Commander US Army Tank Automotive Command ATTN: AMSTA-TSL (Technical Library) Warren, MI 48397-5000
1	Director US Army TRADOC Analysis Command ATTN: ATAA-SL White Sands Missile Range, NM 88002-5502
(Class. only) 1	Commandant US Army Infantry School ATTN: ATSH-CD (Security Mgr.) Fort Benning, GA 31905-5660
(Unclass. only) 1	Commandant US Army Infantry School ATTN: ATSH-CD-CSO-OR Fort Benning, GA 31905-5660
1	The Rand Corporation P.O. Box 2138 Santa Monica, CA 90401-2138
(Class. only) 1	Air Force Armament Laboratory ATTN: AFATL/DLODL Eglin AFB, FL 32542-5000
	Aberdeen Proving Ground Dir, USAMSAA ATTN: AMXSY-D AMXSY-MP, H. Cohen Cdr, USATECOM ATTN: AMSTE-TO-F Cdr, CRDEC, AMCCOM ATTN: SMCCR-RSP-A SMCCR-MU SMCCR-MSI

No. of Copies	Organization	No. of Copies	Organization
1	Commander USA Concepts Analysis Agency ATTN: D. Hardison 8120 Woodmont Avenue Bethesda, MD 20014-2797	4	Project Manager Cannon Artillery Weapons System ARDEC, AMCCOM ATTN: AMCPM-CW AMCPM-CWW AMCPM-CWS/M. Fisette AMCPM-CWA-S/R. DeKline Picatinny Arsenal, NJ 07806-5000
		2	Project Manager Munitions Production Base Moderization and Expansion ATTN: AMCPM-PBM/A. Siklosi AMCPM-PBM-E/L. Laibson Picatinny Arsenal, NJ 07806-5000
		1	Commander US Army Watervliet Arsenal ATTN: SARWV-RD/R. Thierry Watervliet, NY 12189-5001
1	C.I.A. 01R/DB/Standard GE47 HQ Washington, DC 20505		Commander Armament RD&E Center US Army AMCCOM ATTN: SMCAR-LC/LTC N. Barron Picatinny Arsenal, NJ 07806-5000
1	Commander US Army War College ATTN: Library-FF229 Carlisle Barracks, PA 17013		
1	US Army Ballistic Missile Defense Systems Command Advanced Technology Center P.O. Box 1500 Huntsville, AL 35807-3801	2	Director Benet Weapons Laboratory Armament RD&E Center US Army AMCCOM ATTN: SMCAR-CCB-DD Watervliet, NY 12189-4050

No. of Copies	Organization
7	Commander US Army ARDEC ATTN: SMCAR-LCA/ A. Beardell D. Downs S. Einstein S. Westley S. Bernstein C. Roller J. Rutkowski Picatinny Arsenal, NJ 07806-5000
3	Commander US Army ARDEC ATTN: SMCAR-LCB-I/ D. Spring SMCAR-LCE SMCAR-LCM-E/ S. Kaplowitz Picatinny Arsenal, NJ 07806-5000
4	Commander US Army ARDEC ATTN: SMCAR-LCS SMCAR-LCU-CT/ E. Barrieres R. Davitt SMCAR-LCU-CV/ C. Mandala Picatinny Arsenal, NJ 07806-5000
3	Commander US Army ARDEC ATTN: SMCAR-LCW-A/ M. Salsbury SMCAR-SCA/ L. Stiefel B. Brodman Picatinny Arsenal, NJ 07806-5000
2	Commander US Army Tank Automotive Command ATTN: AMSTA-CG Warren, MI 48397-5000
1	President US Army Armor & Engineer Board ATTN: ATZK-AD-S Fort Knox, KY 40121-5200

No. of Copies	Organization
1	Commander US Army Training & Doctrine Command ATTN: ATCD-MA/MAJ Williams Fort Monroe, VA 23651
1	Commander US Materials Technology Laboratory ATTN: SLCMT-ATL Watertown, MA 02172-0001
1	Commander US Army Research Office ATTN: Tech Library P.O. Box 12211 Research Triangle Park, NC 27709-2211
1	Commander US Army Belvoir Research & Development Center ATTN: STRBE-WC Fort Belvoir, VA 23801
1	Commander US Army Logistics Mgmt Ctr Defense Logistics Studies Fort Lee, VA 23801
1	Commandant US Army Command and General Staff College Fort Leavenworth, KS 66027
1	Commandant US Army Special Warfare School ATTN: Rev & Tng Lit Div Fort Bragg, NC 28307
1	Commander US Army Foreign Science & Technology Center ATTN: AMXST-MC-3 220 Seventh Street, NE Charlottesville, VA 22901-5396

No. of Copies	Organization
5	Commander US Army ARDEC ATTN: SMCAR-FSN/K. Chung Picatinny Arsenal, NJ 07806-5000
1	Commandant US Army Field Artillery Center & School ATTN: ATSF-CO-MW/B. Willis Ft. Sill, OK 73503-5600
1	Office of Naval Research ATTN: Code 473/R.S. Miller 800 N. Quincy Street Arlington, VA 2217-9999
1	Commandant US Army Armor School ATTN: ATZK-CD-MS/ M. Falkovitch Armor Agency Fort Knox, KY 40121-5215
2	Commander Naval Sea Systems Command ATTN: SEA 62R SEA 64 Washington, DC 20362-5101
1	Paul Gough Associates, Inc. ATTN: P.S. Gough P.O. Box 1614 1048 South St. Portsmouth, NH 03801-1614
2	Veritay Technology, Inc. ATTN: E. Fisher 4845 Millersport Hwy. P.O. Box 305 East Amherst, NY 14051-0305
1	Sandia National Laboratories ATTN: Div 8152/Neil Lapetina Livermore, CA 94550-0622

No. of Copies	Organization
1	Assistant Secretary of the Navy (R, E, and S) ATTN: R. Reichenbach Room 5E787 Pentagon Bldg Washington, DC 20350
1	Naval Research Laboratory Tech Library Washington, DC 20375
5	Commander Naval Ordnance Station ATTN: P.L. Stang L. Torreyson T.C. Smith D. Brooks Tech Library Indian Head, MD 20640-5000
1	Calspan Corporation ATTN: C. Murphy P.O. Box 400 Buffalo, NY 14255-0400
3	Lawrence Livermore National Laboratory ATTN: L-355/ A. Buckingham M. Finger L-324/M. Constantino P.O. Box 808 Livermore, CA 94550-0622
1	Princeton Combustion Research Laboratory, Inc. ATTN: M. Summerfield 475 US Highway One Monmouth Junction, NJ 08852-9650
2	Director Los Alamos Scientific Laboratory ATTN: T3/D. Butler M. Division/B. Craig P.O. Box 1663 Los Alamos, NM 87544

Aberdeen Proving Ground

Cdr, USATECOM
ATTN: AMSTE-SI-F
AMSTE-CM-F/L. Nealley

Cdr, CSTA
ATTN: STECS-AS-H/R. Hendricksen

USER EVALUATION SHEET/CHANGE OF ADDRESS

... Laboratory undertakes a continuing effort to improve the quality of the reports it publishes. Your comments/answers below will aid us in our efforts.

1. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which the report will be used.) ______

2. How, specifically, is the report being used? (Information source, design data, procedure, source of ideas, etc.) ______

3. Has the information in this report led to any quantitative savings as far as man-hours or dollars saved, operating costs avoided, or efficiencies achieved, etc? If so, please elaborate. ______

4. General Comments. What do you think should be changed to improve future reports? (Indicate changes to organization, technical content, format, etc.) ______

BRL Report Number ______ Division Symbol ______

Check here if desire to be removed from distribution list. ____

Check here for address change. ____

Current address: Organization ______

Address ______

-----------------------------FOLD AND TAPE CLOSED-----------------------------

Director
U.S. Army Ballistic Research Laboratory
ATTN: SLCBR-DD-T(NEI)
Aberdeen Proving Ground, MD 21005-5066

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE $300

NO POSTAGE NECESSARY IF MAILED IN THE UNITED STATES

BUSINESS REPLY LABEL
FIRST CLASS PERMIT NO. 12062 WASHINGTON D C

POSTAGE WILL BE PAID BY DEPARTMENT OF THE ARMY

Director
U.S. Army Ballistic Research Laboratory
ATTN: SLCBR-DD-T(NEI)
Aberdeen Proving Ground, MD 21005-9989